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Contribution of two malacological successions from the Seine floodplain (France) in the reconstruction of the Holocene palaeoenvironmental history of northwest and central Europe: vegetation cover and human impact

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ABSTRACT

Malacological sequences from two archaeological sites on the floodplain of the Seine, Northern France, provide new data on the palaeoenvironmental development of this region during much of the Holocene. Both sites, situated ~100 km apart, have broadly similar sedimentary archives with comparable malacological successions. These Holocene malacological assemblages shed light on the development of the vegetation cover. From the late Neolithic, they reflect open environments, possibly resulting from increasing use of the floodplain for agropastoral activities. These developments are reminiscent of those observed from molluscan assemblages in other regions of northwest and central Europe. The landscape is cleared of trees between 4500 and 1200 cal BC. At the end of the Subboreal, it is dominated by agricultural land.

1. Introduction

Rescue archeology has developed considerably in France over the last thirty years. In this context, the Paris Basin, which is a geological region centered on the city of Paris, has been the subject of numerous investigations due to its significant economic development in recent decades. The extensive fieldwork undertaken during this period has resulted in broad multidisciplinary studies of ancient landscapes combining geomorphology and several biological proxies (Pastre et al., 1997, 2000, 2001, 2002a, 2002b, 2003). In northern France, the study of important malacological sequences dating from the Lateglacial (Limondin-Lozouet and Antoine, 2001; Limondin-Lozouet, 2012) and from the first half of the Holocene (Limondin-Lozouet and Preece, 2004; Limondin-Lozouet et al., 2013), has led to the construction of a series of regional malacozones, which provide a temporal framework into which other sites can be fitted. In the Paris Basin, despite the recent proliferation of malacological studies undertaken on archaeological sites dating from the second half of the Holocene, no synthesis has yet been attempted. As a result, the palaeoenvironmental developments of this period are reconstructed only using pollen analyses, which have been integrated with geomorphological data (Leroyer, 1997, 2003, 2004, 2006; Leroyer and Allenet, 2006; Leroyer et al., 2012). Pollen is generally preserved in waterlogged horizons, which are best developed in close proximity to river channels. The shells of molluscs occur in many types of calcareous sediment, both in waterlogged locations, and in places where oxidation has destroyed the pollen, as is the case on many floodplains. Floodplain sequences are complex because of their discontinuous nature, necessitating the sampling of several profiles at each site in order to reconstruct the full stratigraphical succession. However, in many places, the repeated deposits of alluvium in floodplains have favoured the formation of stratified sequences, which are conducive to a chronological approach of palaeoenvironmental changes recorded by the malacological successions. In addition, floodplains are frequently more closely associated with archaeological settlements than are most pollen sampling locations. The alluvial floodplain of the Seine, the main river that crosses Northern France, has been

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extensively investigated in recent years. We will focus on two specific areas: the first is located in the Paris region, in the mid-section of the Seine; the second is situated ~100 km downstream, at the confluence of the Seine and the Eure, in the Upper-Normandy region (Fig. 1). Do the malacological sequences follow a common ecological trajectory in both regions? Do they show similar trends with other European malacological successions?

2. Stratigraphy and chronology

The two case studies reported here are quite different: one is located in a dense urban zone, the Paris region, whereas the other is situated in a rural area, at the confluence of the Seine and one of its tributaries. The sampled profiles represent the Lateglacial and Holocene fine-grained sediments that overlie sands and gravels dating from the Upper Pleistocene. These alluvial deposits are several metres thick and yield some archaeological layers dating from the Epipalaeolithic to the Middle Ages.

2.1. Paris, Héliport/Farman

The site of *Héliport/Farman* is situated on the left bank of the Seine, in a place where the floodplain width is ~1 km from east to west and between 25 and 30 m asl (Fig. 2a). It covers ~1 ha in the 15th district of Paris and is actually the combination of two adjacent excavations (Fig. 2b) that have been undertaken, in 1996, at the *Héliport DGAC* (Watrin et al., 1996) and, in 2008, at the *62 rue Henry Farman* (Souffi and Marti, 2011; Souffi et al., 2013). Despite the fact that the *Héliport DGAC* site is located on a small mound (profile S1), the altitudinally lower *62 rue Henry Farman* site (profiles 601 and 201) displays the same sedimentary succession and similar archaeological archives (Fig. 2c).

Coarse sands and gravels from the Pleniglacial are directly overlain by archaeologically sterile marly silts (profiles S1 and 201), which become sandy in a lateral depression (profile 601). These silts, which are more than 1 m thick, are overlain by orange–brown clays containing Mesolithic industries distributed in six concentrations of lithic and bone remains. At *Rue Farman*, two radiocarbon dates obtained from bones collected at the base of this clayey layer have given ages of 9285 ± 40 BP and 8805 ± 40 BP, i.e. between 8633–8349 and 8197–7728 cal BC (Table 1). However, the flint arrow-head typology suggests the occurrence of several diachronic settlements at least until ~7000 cal BC. Locally, the orange–brown clayey layer containing Mesolithic artefacts is thicker and contains some ceramic remains (profile 201). Despite the absence of associated radiocarbon dates, the typology of these remains suggests their attribution to the middle Neolithic, i.e. between 4200 and 3500 cal BC. An abrupt stratigraphic boundary is then marked by the development of dark brown clayey silts attributed to the late Neolithic and early Bronze Age (from 2500 to 1500 cal BC) on archaeological evidence. In the upper part of these silts, several concentrations of charcoals and a human cremation give ages between 3735 ± 185 BP and 3020 ± 60 BP, i.e. between 2835–1660 and 1420–1059 cal BC (Table 1). These radiocarbon dates are consistent with a broad cultural attribution of this layer to the Bronze Age. In the southern part of the site (profile 201), an important lateral lithostratigraphic variation is formed by a thin sandy silt layer (Fig. 2c). This layer is overlain by clayey silts containing some fragments of pottery dating from the Hallstatt period. At the *Héliport DGAC* site (profile S1), despite the absence of this marker layer, similar ceramic evidence are found in the dark brown clayey silts (Fig. 2c). Three radiocarbon dates are associated with this archaeological layer (Table 1): two of them are consistent with the cultural attribution based on artefacts (Poz-5473 and UPS C 4427) but the third is anomalously old (8590 ± 40 BP; BETA-326102), indicating the substantial reworking of charcoals dating from the early Holocene. Homogeneous light brown sandy silts lastly mantle the entire site. This layer is archaeologically sterile but is incised by a channel that is still discernible in the cartographic archives until the eighteenth centuries (Watrin and Gaillard, 1995).

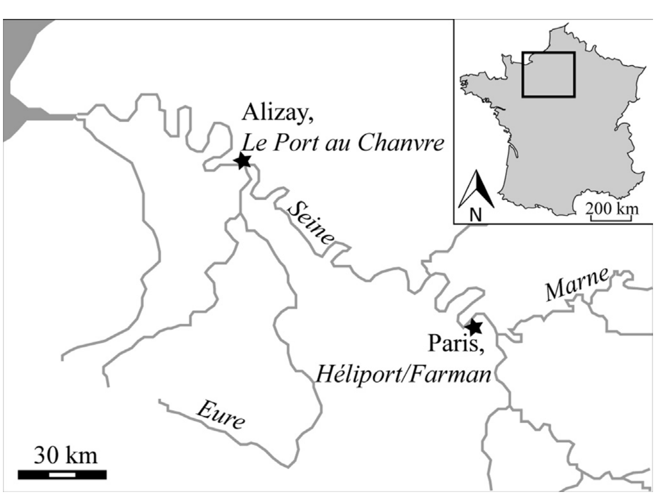

Fig. 1. Location of Paris *Héliport/Farman* and Alizay *Le Port au Chanvre*.

2.2. Alizay, Le Port au Chanvre

In recent years, several archaeological sites have been found on the banks of the Seine River in Upper Normandy. Most of these sites are associated with the aggregate industry, the development of which has provided the opportunity to explore floodplain sites in a rural setting, on larger plots than in urban area. Several archaeological sites have recently been found in Alizay (Marcigny et al., 2013). Approximately 15 ha have already been investigated and the exploration of further 15 ha is planned before the end of this decade. The results presented here are thus a part of an on-going work. The site is located on the right bank of the Seine, at an elevation between 5 and 10 m asl, on a flat-land exceeding 1 km width from north to south (Fig. 3a). Three malacological profiles have been analysed in this area: two come from a sandy mounds and the third from a bank of a palaeochannel (Fig. 3b). The stratigraphic succession observed at Alizay is largely uniform, although some lateral variations of sedimentary facies are apparent, as well as some hiatuses (Fig. 3c).

The Weichselian gravels are overlain by grey clayey sands, which are in turn covered by thick light grey silts. The first archaeological layer, involving Epipalaeolithic artefacts dating from the turn between the Younger Dryas and the Preboreal (BETA-317897, BETA-333638, BETA-333640, BETA-322721; Table 2), occurs at the transition between these silts and a silty clay. The Epipalaeolithic settlement consists of more than 4500 flints and bones distributed over a circular area of approximately 70 m^2 (Marcigny et al., 2013). The overlying silty clay locally contains artefacts dating from the middle Mesolithic (BETA-317893, BETA-322719; Table 2). Above this layer, brown clayey silts, getting more clay-rich (and consequently heavier) in the close proximity of palaeochannels (profile C2-25), contain artefacts dating from the middle Neolithic to the early Bronze Age (between 5440 ± 20 and 3755 ± 30 BP; Table 2). The middle Neolithic remains are organized into several knapping spots and hearths set up along channels. The remains dating from the late

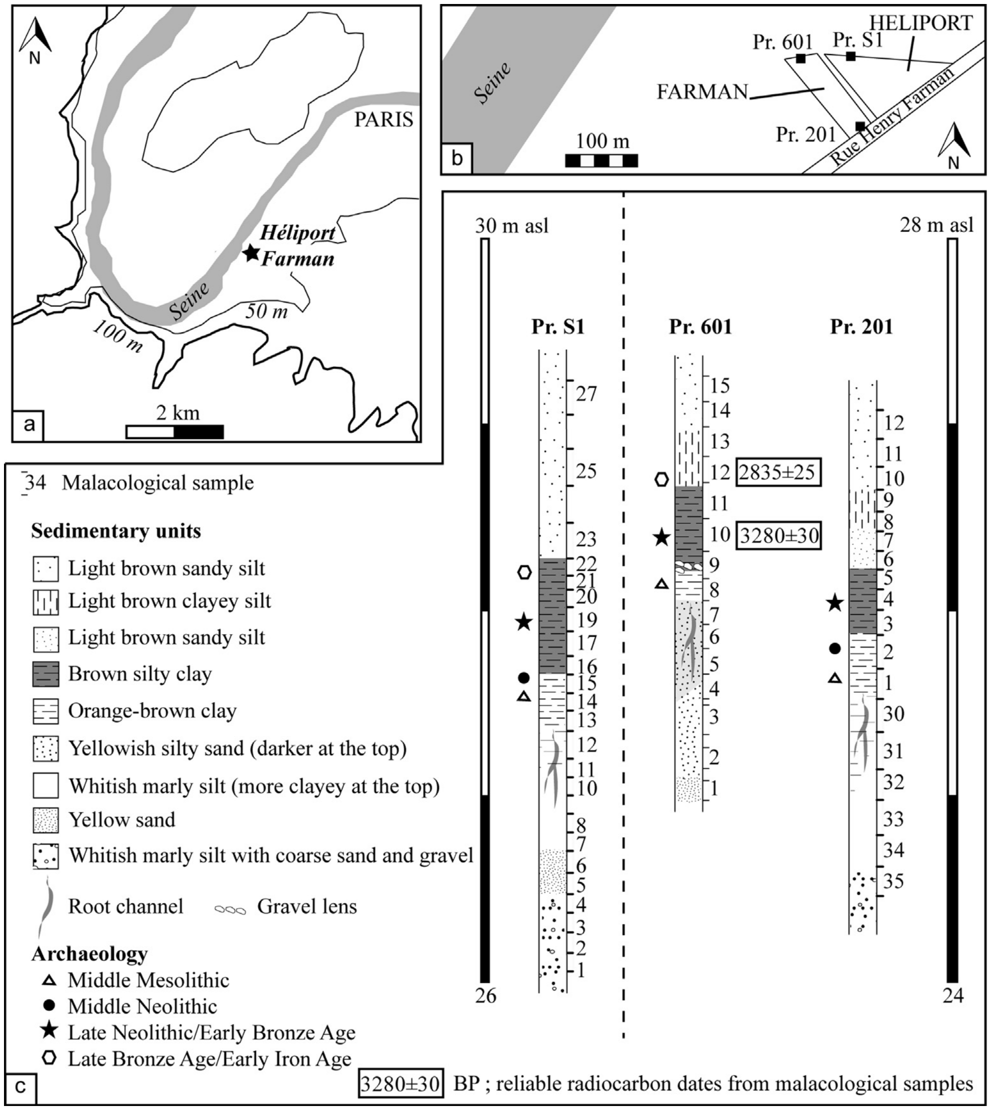

Fig. 2. Paris, *Héliport/Farman*. Position of the site (a) and of sampling locations (b). Chronostratigraphy and position of malacological samples (c). For more details about radiocarbon dates see Table 1.

Neolithic and early Bronze Age occur at the transition with the upper level, consisting of lighter clayey silts. A date directly obtained on charcoals extracted from a malacological sample from the base of this layer (BETA-326100; Table 2) has given an age of 3810 ± 40 BP (2456–2137 cal BC). This layer does not extend across the entire site and its preservation is determined by the palaeotopography. Another unit of silts, locally containing artefacts from the Iron Age, is then emplaced. Two dates are consistent with its archaeological attribution (Poz-53266, ULA-2870; Table 2). Finally, the site is covered by light brown sandy silts associated with a medieval military encampment, dating from the ninth century BC, found on the adjacent parcel. A radiocarbon date obtained in a malacological sample from this layer is anomalously old (Poz-53265; Table 2) and might indicate the formation of this layer as early as the late Iron Age (La Tène culture).

3. Malacological analyses

In this section, after a brief presentation of the methodology, malacozones of each site are then defined.

3.1. Methodology

Each sequence analysed has been sampled from a continuous column, broadly respecting the lithostratigraphic boundaries. For each sample, 8 L of sediments have been collected and then sieved on a mesh of 500 microns. After sieving and sorting, the component species of the assemblage have been quantified. In order to simplify the data, each species has been assigned to a particular ecological group. Different systems of ecological classification have been created by European malacologists (Boycott, 1934; Sparks, 1961; Ložek, 1964; Evans, 1972; Puisségur, 1976). These ecological classifications result from experience gained from different parts of Europe, which explains some of their minor differences. For instance, the ecological requirements of certain species differ between Mediterranean, alpine or Atlantic regions. The classification system used here is based on Puisségur's works (1976) on the modern faunas from Burgundy (France) but it has been simplified. It is essentially based on moisture requirements and the amount of the vegetation cover. Since floodplains are the focus of this project, aquatic species characteristic of permanent water-bodies have all been assigned to a single group. More distinctions have been used

Table 1
Paris, *Héliport/Farman*. Radiocarbon dates. Calibrations were performed in reference to the curve IntCal 13 (Reimer et al., 2013). The date in grey is doubtful.

Lab. code	Material	BP	cal BP	cal BC
GRA-45018	Bone (aurochs)	9285 ± 40	10,582–10,298	8633–8349
GRA-45017	Bone (wild pig)	8805 ± 40	10,146–9677	8197–7728
UPS C 4450	Charcoal (pit)	4630 ± 110	5590–4979	3641–3030
UPS C 4422	Charcoal (concentration)	3735 ± 185	4784–3609	2835–1660
UPS C 4426	Charcoal (concentration)	3635 ± 90	4230–3699	2281–1750
UPS C 4425	Charcoal (concentration)	3365 ± 65	3825–3451	1876–1502
BETA-326103	Charcoal (mix)	3280 ± 30	3579–3446	1630–1497
UPS C 4448	Charcoal (cremation)	3020 ± 60	3369–3008	1420–1059
UPS C 4427	Charcoal (concentration)	2805 ± 50	3057–2785	1108–836
POZ-54736	Charcoal (mix)	2835 ± 25	3020–2862	1071–913
BETA-326102	Charcoal (mix)	8590 ± 40	9657–9493	7708–7544

for amphibious species (e.g. *Galba truncatula*) and those able to live in temporary pools, such as *Anisus spirorbis*. Regarding land snails, some of these also reflect changes in moisture, particularly marshland species, increasing when conditions become wetter. In relation to the vegetation cover, terrestrial species have been assigned to three main groups: the first includes shade-demanding taxa and the last those of open-ground. An intermediate group includes mesophile species, able to inhabit a wide range of biotopes. This ecological classification of molluscs is used as the basis for palaeoenvironmental reconstructions (ecological spectra) as well as the specific composition of faunal assemblages (diagrams).

3.2. Malacozones from Paris, Héliport/Farman

The full dataset from *Héliport/Farman* have been published elsewhere (Granai et al., 2011), so the lists of fauna are not presented here. Ecological spectra and diagrams are nevertheless provided for each column (Figs. 4–6).

PHF-T This first malacozone is only identified on the profile S1 (Fig. 4). It is characterized by assemblages poor in both species and specimens. The three dominant terrestrial species (*Pupilla muscorum*, *Vallonia costata* and *Trochulus hispidus*) can be considered as pioneer taxa in an inhospitable environment (such as a bare ground). In addition, the diversity of aquatic species indicates major flooding events.

PHF-I Malacological assemblages of *PHF-I* contain many more species and in far greater abundance than during the previous zone. In the northern part of the site (profiles S1 and 601), this faunal shift occurs gradually, enabling the definition of two subdivisions (Figs. 4 and 5). In the first (*PHF-Ia*), *V. costata* and *T. hispidus* persist in high frequencies from the previous zone but are here joined by *Aegopinella nitidula*, a shade-demanding mollusc. In this subdivision, the number of both specimens and species remains relatively low, particularly compared to the later subdivision (*PHF-Ib*). In *PHF-Ib*, several species are actually represented by significant numbers of specimens, particularly those able to inhabit woodland, but mesophile and grassland species are also well represented. This high diversity shows that molluscs clearly have the use of a patchwork of habitats to find shelter and food. This two stage development of the *PHF-I* zone finally reflects the progressive expansion of the vegetation cover in the floodplain. The low number of freshwater species furthermore indicates the rarity of flooding events.

PHF-II Malacological assemblages attributed to this malacozone are typified by an important decrease of shade-demanding taxa, principally in favour of one single species, *Vallonia pulchella*, which is characteristic of wet meadows. The only shade-demanding species maintaining relatively large numbers of specimens is *Clausilia bidentata*, described as tolerant to human disturbance (Evans, 1972). Two hygrophilous species, *Carychium minimum* and *Succinella oblonga*, show appreciable increases. Locally, where the decline of woodland species is the most abrupt (profile 201), the proportions of *G. truncatula* and *A. spirorbis* significantly increase (Fig. 6), indicating temporarily inundated environments. Despite some local variations from one profile to another, the malacological assemblages generally reflect more open and moist environments.

PHF-III In this last malacozone, *V. pulchella*, the dominant species in the previous zone, becomes even more abundant and the frequencies of *T. hispidus*, *C. minimum* and *S. oblonga* decline. The only species that increase in frequency are *P. muscorum* and *Helicella itala*. This association (*V. pulchella*/*P. muscorum*/*H. itala*) points to a homogeneous short-turfed grassland. At the top of profiles 201 and 601, an increase of freshwater molluscs is observed. Molluscs able to live in temporary pools are virtually absent, indicating the existence of major flood events. The detection of such flood events nevertheless depends on the palaeotopography. In profile S1, located on a small mound, no evidence of flooding can be detected (Fig. 4) but clear evidence of flooding occurs in the lowest part of the site (profile 201; Fig. 6).

3.3. Malacozones from Alizay, Le Port au Chanvre

Data from Alizay are new. The discussion is thus accompanied by a full set of lists of fauna (Appendices A–C), ecological spectra and diagrams (Figs. 7–9).

ALZ-T1 In the profile C2-25, this first malacozone consists of an assemblage rich in shells but poor in species (Fig. 8). *P. muscorum*, an inhabitant of open ground, dominates, representing >80% of the total assemblage. The occurrence of *Xerocrassa geyeri* is noteworthy because this species of dry open grassland is absent in Northern France today (Kerney and Cameron, 1979). Freshwater molluscs are rare and evenly distributed among several species, probably resulting from minor flood events. In the profile C1-1, the low number of shells recovered precludes an attribution to a particular malacozone but the dominance of *P. muscorum* nevertheless suggests an attribution to *ALZ-T1* (Fig. 7).

ALZ-T2 The number of shells decline suddenly in this zone. In profile C1, *ALZ-T2* is typified by freshwater species (Fig. 7), in particular by *Bithynia tentaculata* (Appendix A), here essentially represented by opercula. A partial destruction of shells together with an alteration of the sediment is suspected since opercula are heavier than shells and less brittle. The assemblages from profile C2-25, which are attributed to *ALZ-T2* with caution, are more diverse but the total number of shells recovered remains low (Fig. 8). *P. muscorum*, *V. costata* and *T. hispidus* are dominant, indicating the occurrence of sparse and low vegetation. However, the diversity increases, especially because of the presence of several woodland species. This questions the attribution of this malacozone to the Lateglacial (see Section 3.2.).

ALZ-I This zone is differentiated from the previous one by a substantial increase of the number of specimens. No one species dominates and an even distribution of specimens is observed between species with different ecological requirements (Figs. 7–9). The environment appears to be diverse with light woodland, sunny grassland and marshland, but there is a possible mix of assemblages from varying ages (see Section 3.2.). Shade-demanding taxa nevertheless represent between 20 and 40% of the total assemblage.

ALZ-II This malacozone is merely identified in the profile C2-25 (Fig. 8). The two samples that are attributed to *ALZ-II* differ in

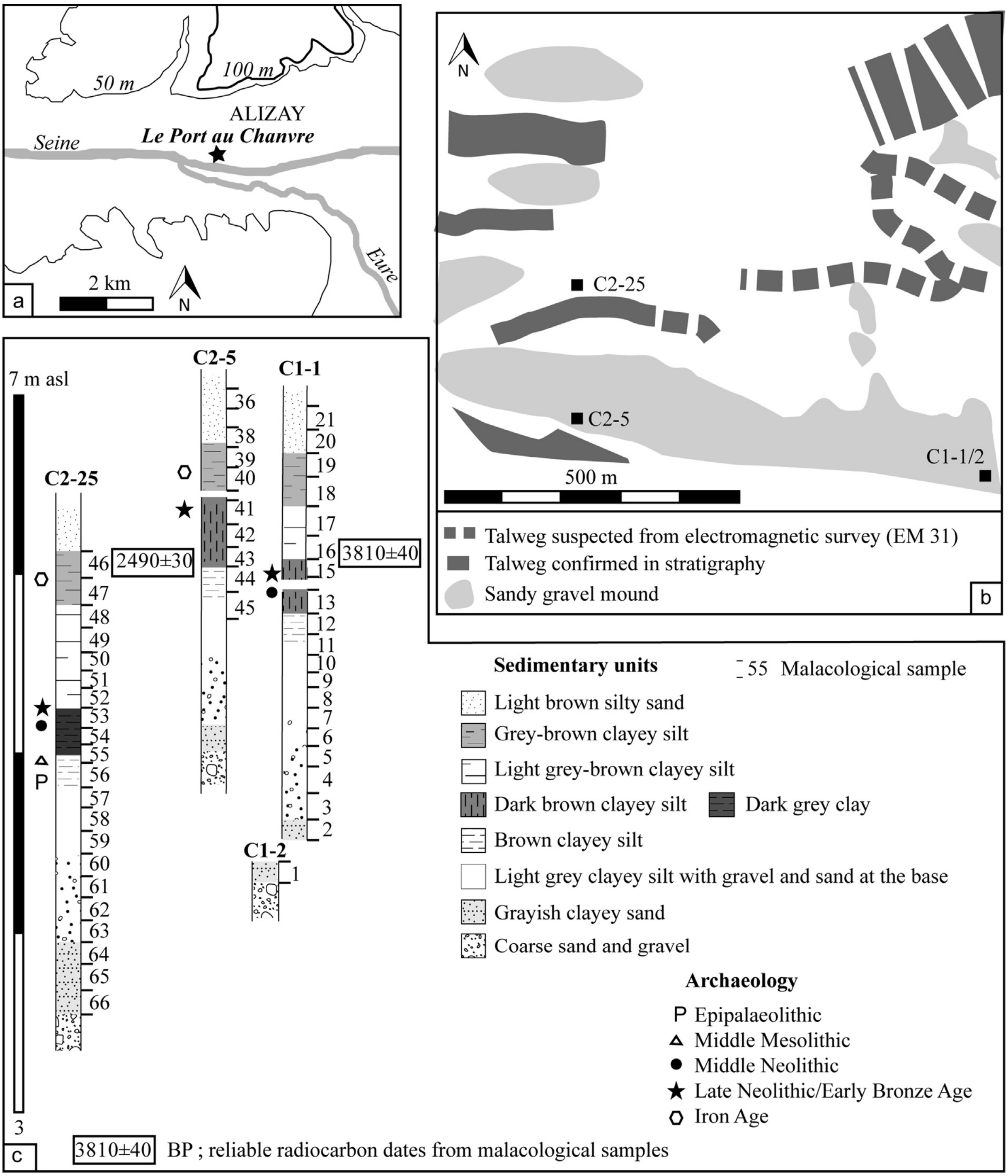

Fig. 3. Alizay, *Le Port au Chanvre*. Position of the site (a) and of sampling locations (b). Chronostratigraphy and position of malacological samples (c). For more details about radiocarbon dates see Table 2.

number of specimens. An unfavourable phase to the development or conservation of shells occurs in the sample No. 54: it is characterized by a sharp decline in the number of specimens. Despite this local disruption of the malacological signal, both samples display comparable assemblages. In *ALZ-II*, the shade-demanding species decline in favour of open-ground species, especially of *V. pulchella*.

ALZ-III In the profile C2-25, which is located close to a palaeochannel, the malacozone *ALZ-III* is characterized by a dramatic increase of freshwater molluscs (Fig. 8). Actually, there is a two stage development of these faunas. First (*ALZ-IIIa*), land snails are poorly represented and there is a diverse aquatic assemblage, reflecting the proximity of a slow stream. Then (*ALZ-IIIb*), the development of a swamp environment is reflected by the dominance of the amphibious species *G. truncatula* (Appendix B) and the expansion of terrestrial molluscs (Fig. 8). In profile C1, located on a terrace situated >100 m from this damp environment, aquatic molluscs are scarce (Fig. 7). The wet grassland species *V. pulchella* is dominant together with the mesophile *T. hispidus* and the marshland species *C. minimum*. In addition, the low amount of shade-demanding taxa enables the reconstruction of open environments.

Table 2
Alizay, *Le Port au Chanvre*. Radiocarbon dates. Calibrations were performed in reference to the curve IntCal 13 (Reimer et al., 2013). The date in grey is doubtful.

Lab. code	Material	BP	cal BP	cal BC
BETA-333638	Tooth (aurochs)	10,100 ± 40	11,969–11,404	10,020–9455
BETA-333640	Antler (reindeer)	9960 ± 40	11,606–11,253	9657–9304
BETA-317897	Tooth (aurochs)	9890 ± 40	11,393–11,220	9444–9271
BETA-322721	Bone (aurochs)	9610 ± 50	11,167–10,766	9218–8817
BETA-322719	Charcoal (locus)	8940 ± 40	10,205–9915	8256–7966
BETA-317893	Charcoal (locus)	8840 ± 50	10,159–9705	8210–7756
ULA-2674	Charcoal (pit)	7060 ± 20	7945–7848	5996–5899
ULA-2509	Charcoal (hearth)	5440 ± 20	6290–6208	4341–4259
ULA-2842	Charcoal (hearth)	5425 ± 20	6286–6202	4337–4253
ULA-2642	Charcoal (hearth)	5415 ± 20	6281–6195	4332–4246
ULA-2888	Charcoal (hearth)	5295 ± 30	6184–5955	4235–4006
AA-95780	Bone (burial)	5230 ± 60	6185–5900	4236–3951
ULA-2838	Charcoal (hearth)	5050 ± 25	5897–5736	3948–3787
ULA-2802	Charcoal (hearth)	4995 ± 25	5876–5653	3927–3704
ULA-2841	Charcoal (pit)	4440 ± 20	5276–4962	3327–3013
ULA-2843	Charcoal (posthole)	4390 ± 20	5039–4869	3090–2920
ULA-2658	Charcoal (locus)	4375 ± 20	5032–4865	3083–2916
ULA-2671	Charcoal (locus)	4335 ± 15	4960–4850	3011–2901
ULA-2525	Charcoal (pit)	3860 ± 24	4410–4160	2461–2211
BETA-326100	Charcoal (mix)	3810 ± 40	4405–4086	2456–2137
ULA-2886	Charcoal (hearth)	3755 ± 30	4233–3990	2284–2041
ULA-2528	Charcoal (pit)	3700 ± 23	4144–3974	2195–2025
ULA-2645	Charcoal (mix)	2760 ± 15	2919–2790	970–841
Poz-53266	Charcoal (mix)	2490 ± 30	2730–2460	781–511
ULA-2870	Charcoal (posthole)	2335 ± 25	2420–2315	471–366
Poz-53265	Charcoal (mix)	2140 ± 30	2302–2006	353–57

ALZ-IV This zone is marked by the virtual disappearance of shade-demanding taxa. *V. pulchella* remains dominant and is still associated with *T. hispidus* but *C. minimum* almost vanishes to the benefit of *S. oblonga*, a hygrophilous species generally inhabiting wet bare ground (Fig. 7). This extremely low diversity suggests a short and homogeneous vegetation cover. The aquatic fauna consists mainly of *Valvata* and *B. tentaculata*, suggesting flood deposits (Appendix A).

4. Results: the palaeoenvironmental succession and its chronology

Both sites yield comparable malacological assemblages, allowing the synthesis of their results.

4.1. The Lateglacial and its boundary with the early Holocene

At Alizay, the composition of the assemblages of *ALZ-T1*, and especially the occurrence of *X. geyeri*, allows the attribution of this malacozone to the Allerød. In the valleys of the Paris Basin (Limondin, 1995; Pastre et al., 2000, 2003), and elsewhere in NW Europe (Limondin Lozouet, 2002), the Allerød is characterized by assemblages rich in specimens, dominated by taxa of open-ground, such as *P. muscorum* and *Vallonia*, but also includes drought-tolerant species, such as *X. geyeri* and *Helicopsis striata*, absent today from the Paris Basin (Kerney and Cameron, 1979). In this region, a buried grey soil has formed at several sites during the Allerød chronozone. Many of these sites have yielded an Azilian archaeology, such as at Rueil-Malmaison *Le Closeau*, located ~10 km to the west of Paris *Héliport/Farman* (Limondin-Lozouet, 1997).

The malacozones *ALZ-T2* and *PHF-T* are broadly similar. They consist of low numbers of terrestrial specimens and present substantial frequencies of aquatic taxa. The malacological assemblages from both sites indicate the existence of poorly vegetated surfaces subject to extensive flooding. Similar molluscan assemblages occur in valleys of NW Europe during the Younger Dryas (Limondin-Lozouet, 1998, 2002). At Conty (Oise, France), which is a reference site for the malacological assemblages of this chronozone, an initial stage is marked by a virtual absence of fauna whereas a second stage is characterized by more abundant assemblages (Limondin-Lozouet and Antoine, 2001; Limondin-Lozouet, 2012). The reference to the malacological successions derived from Conty suggests an attribution of *ALZ-T2* and *PHF-T* to the first stage of the Younger Dryas. However, the lack of any dating elements precludes the confirmation of this hypothesis. Furthermore, the presence of a few thermophilous species seriously questions this assumption of chronological attribution. Regarding *PHF-T*, an attribution to the Lateglacial is suggested on the basis of the absence of shade-demanding taxa in the samples No. 1, 2 and 3 of S1 profile but is questionable for the sample No. 4, where three specimens of three different woodland species have been collected. Referring to these specimens, the limit between *PHF-T* and *PHF-I* might be situated between the samples No. 3 and No. 4. However, in the sample No. 4, the number of shells is still low and there is no lithologic variation compared with the previous samples, whereas in the sample No. 5, the increased number of shells, the change in lithology and the higher diversity of shade-demanding taxa justify an attribution of this sample to a new malacozone, undoubtedly dating from the Holocene. An attribution of *PHF-T* to the Preboreal is nevertheless possible, the beginning of this chronozone being regionally characterized by a phase of incision affecting the Younger Dryas deposits (Antoine, 1997; Antoine et al., 2003; Le Jeune et al., 2012; Pastre et al., 2002a, 2002b). At Alizay *Le Port au Chanvre*, it is also difficult to propose a clear chronological attribution of *ALZ-T2*. The thermophilous specimens are scarce in the C1 profile but more numerous in C2-25. The occurrence of these shells is problematic and is discussed in more detail below (see Section 3.2).

4.2. Preboreal and Boreal chronozones

At Paris *Héliport/Farman*, the first malacozone attributed to the Holocene is divided in two steps. The first division, named *PHF-Ia*, is typified by an increase in woodland species within assemblages dominated by open-ground and mesophile taxa. In NW Europe, the transition from the Preboreal to the Boreal is marked by the succession of two species of *Discus* (Limondin-Lozouet, 2011; Preece and Bridgland, 1999). *Discus ruderatus*, which lives today in boreo-alpine regions, appears first, and then co-exists with *Discus rotundatus* before finally being replaced by this species. *D. rotundatus*, which is still common in the Paris Basin (and throughout much of NW Europe), lives in deciduous woodlands (Kerney and Cameron, 1979). At the site in Paris, *D. ruderatus* is totally absent but this absence is not a sufficient argument to exclude the recognition of the Preboreal. Indeed, in *PHF-Ia*, the low diversity of species, high frequencies of *V. costata* and low frequencies of *D. rotundatus* are three good arguments to attribute these assemblages to the Preboreal. The occurrence of *D. rotundatus* beneath a layer yielding bones radiocarbon-dated to 9285 ± 40 BP and 8805 ± 40 BP (Table 1) suggests an anomalously early appearance of this species. Indeed, the arrival of *D. rotundatus* is dated from 9074 ± 63 BP in Lower Normandy (Limondin-Lozouet and Preece, 2004; Limondin-Lozouet et al., 2005), shortly before 8830 ± 90 BP in the Somme valley (Limondin, 1995; Limondin-Lozouet and Antoine, 2001), between 8900 and 8100 BP in United-Kingdom, depending on regions (Kerney et al., 1980; Preece and Day, 1994; Preece and Bridgland, 1999; Preece, 1997; Meyrick and Preece, 2001) and between ~8500 and 8400 BP in western Germany and Luxembourg (Meyrick, 2001). As far as today, the *D. rotundatus* specimens from Paris would be the oldest record of this species in NW Europe. The more southerly location of Paris

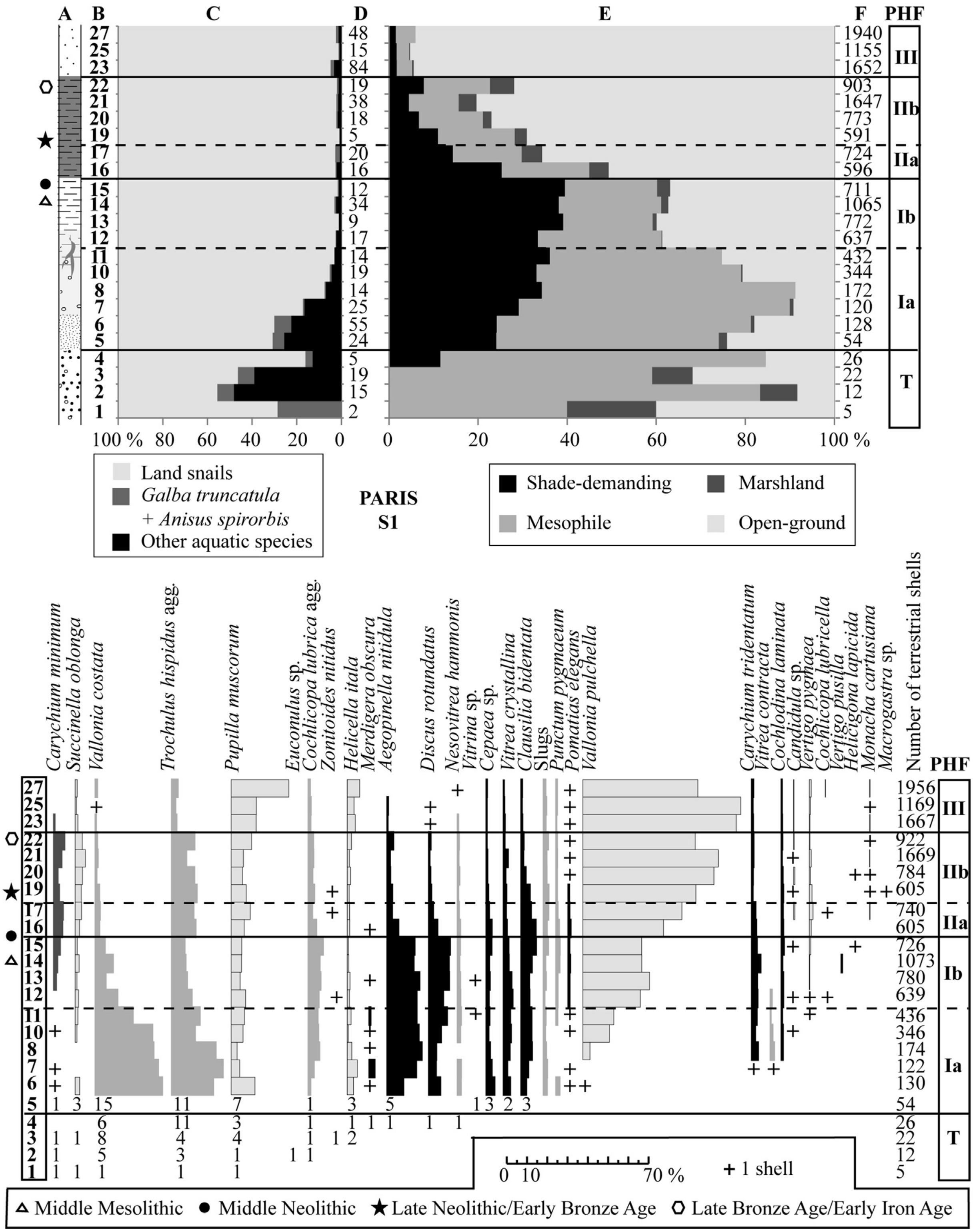

Fig. 4. Paris, *Héliport/Farman*, profile S1. Ecological and specific composition of malacological assemblages. A: Schematic stratigraphical profile (see Fig. 2); B: Sample number; C: Frequency and distribution of aquatic shells; D: Number of aquatic shells; E: Ecological classification of terrestrial shells; F: Number of terrestrial shells.

might explain this older occurrence but this hypothesis should be tested on other sites excavated in this region in the coming years.

In *PHF-Ib*, *D. rotundatus* is well represented (5–15% of assemblages). In addition, there are more species and the shade-demanding taxa represent between 20 and 40% of the assemblages. These features are characteristic of a later stage of the Holocene, when more stable conditions have favoured the development of the vegetation cover, providing a wider range of habitats for snails. References to the malacological framework from tufa deposits in Northern France (Limondin-Lozouet and Preece, 2004;

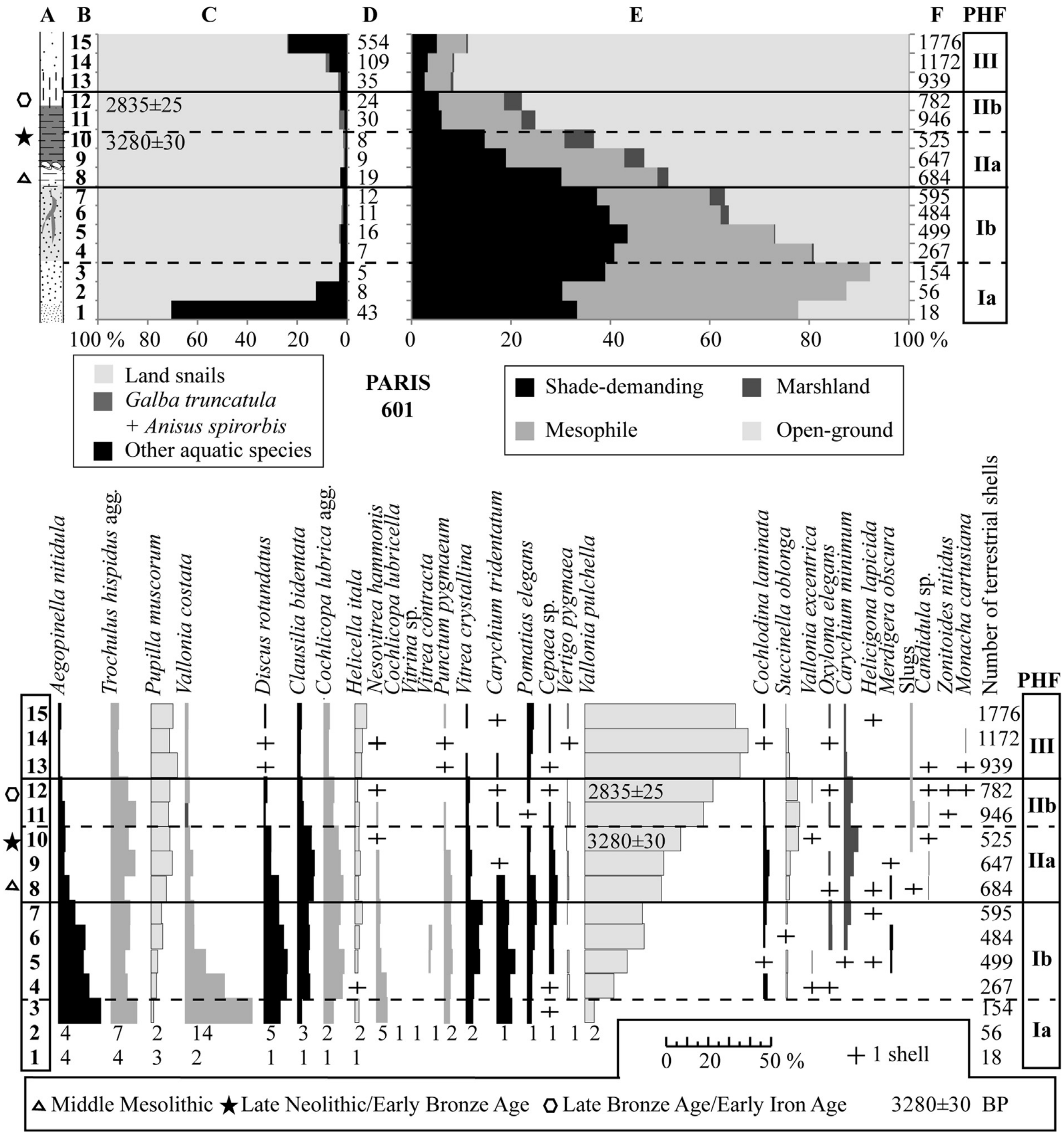

Fig. 5. Paris, *Héliport/Farman*, profile 601. Ecological and specific composition of malacological assemblages. A: Schematic stratigraphical profile (see Fig. 2); B: Sample number; C: Frequency and distribution of aquatic shells; D: Number of aquatic shells; E: Ecological classification of terrestrial shells; F: Number of terrestrial shells.

Limondin-Lozouet et al., 2013) suggest that a Boreal age is probable. This attribution is supported by the presence of archaeological remains dating from the middle Mesolithic.

At Alizay, the association of *D. rotundatus* and of a wide range of thermophilous species beneath artefacts belonging to the Epipalaeolithic raises serious concerns about the stratigraphical integrity of the malacological succession. This mismatch between the ages of sediments and their faunas is problematic. The problematic Holocene shells might have been introduced into older sediments. The occurrence of the problematic taxa would then results from intrusion from the overlying sediments, either along root channels or from other forms of bioturbation (earthworms, burrows) associated with an extended pedogenesis of the Holocene soil. As observed at Alizay, it is therefore doubtful that the malacological assemblages dating from the early Holocene are always in primary context.

4.3. Atlantic chronozone

The layers in the upper part of the sequences yielding the *ALZ-I* and *PHF-Ib* assemblages are thin and associated with archaeological remains dating from various periods. These remains would indicate that the floodplain stability has lasted several millennia. However, the absence, at Paris *Héliport/Farman*, or the extreme rarity, at Alizay *Le Port au Chanvre*, of archaeological remains dating from the late Mesolithic and early Neolithic, i.e. between 7000 and 4500 cal BC, might indicate the existence of less stable conditions. At the Paris site, an erosive phase is demonstrated by a gravel lens

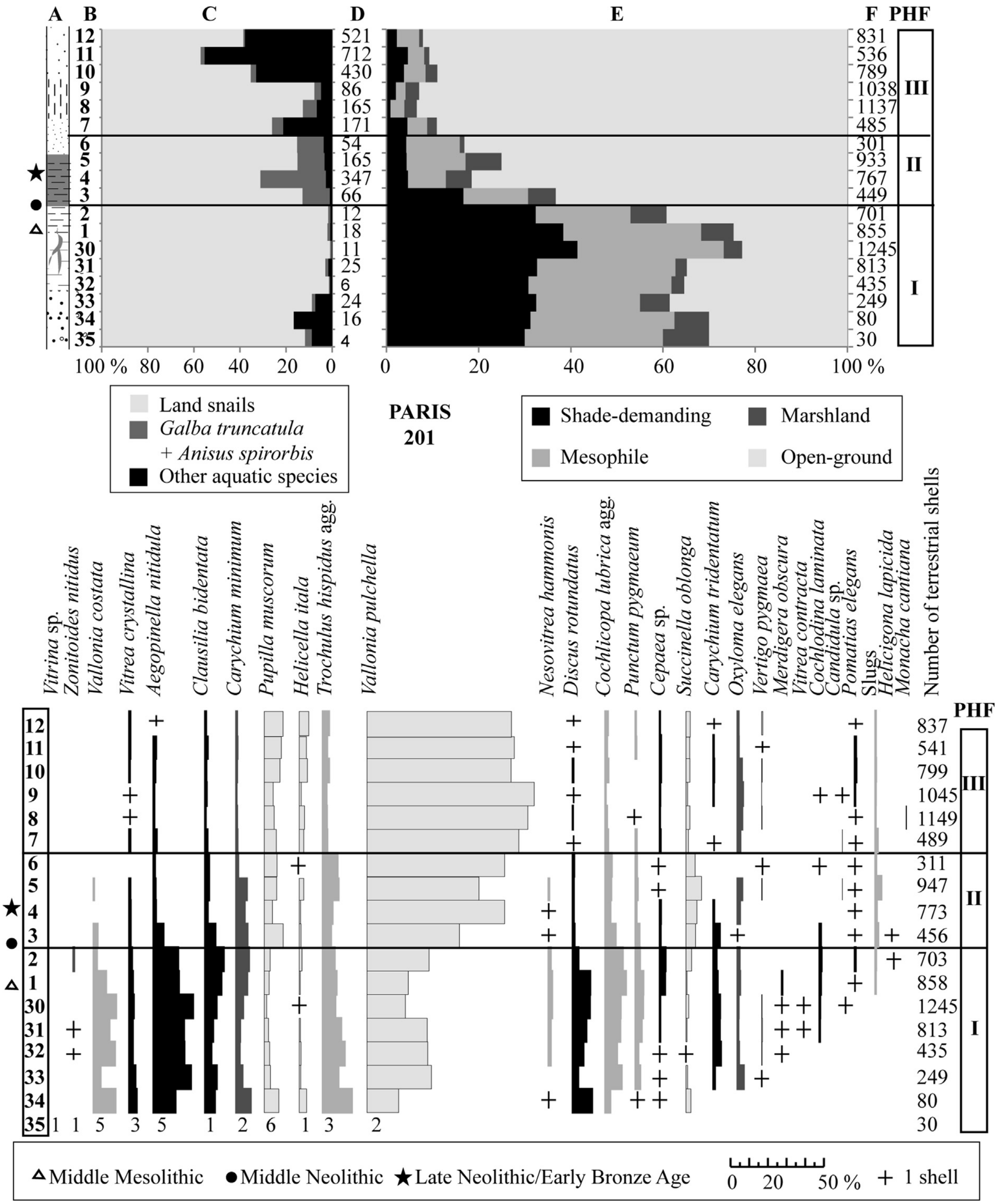

Fig. 6. Paris, *Héliport/Farman*, profile 201. Ecological and specific composition of malacological assemblages. A: Schematic stratigraphical profile (see Fig. 2); B: Sample number; C: Frequency and distribution of aquatic shells; D: Number of aquatic shells; E: Ecological classification of terrestrial shells; F: Number of terrestrial shells.

separating the middle Mesolithic artefacts from those dating from the middle Neolithic (profile 601; Fig. 2c). A comparable episode is suggested at Alizay, where the archaeological remains dating from the late Mesolithic and early Neolithic are located on a small sandy mound (Marcigny et al., 2013). However, it is unlikely that the sites dating from these periods have been eroded. The choice of location for human activity was probably dependent upon a number of factors, including environmental as well as cultural and economic.

4.4. Subboreal chronozone

ALZ-II, *ALZ-III* and *PHF-II* consist of assemblages reflecting more open and moist environments. The oldest archaeological evidence associated with these malacozones date from the middle Neolithic, at the turning point between the Atlantic and the Subboreal. At Paris *Héliport/Farman*, evidence of this archaeological period is limited to a few scattered artefacts, while at Alizay, numerous

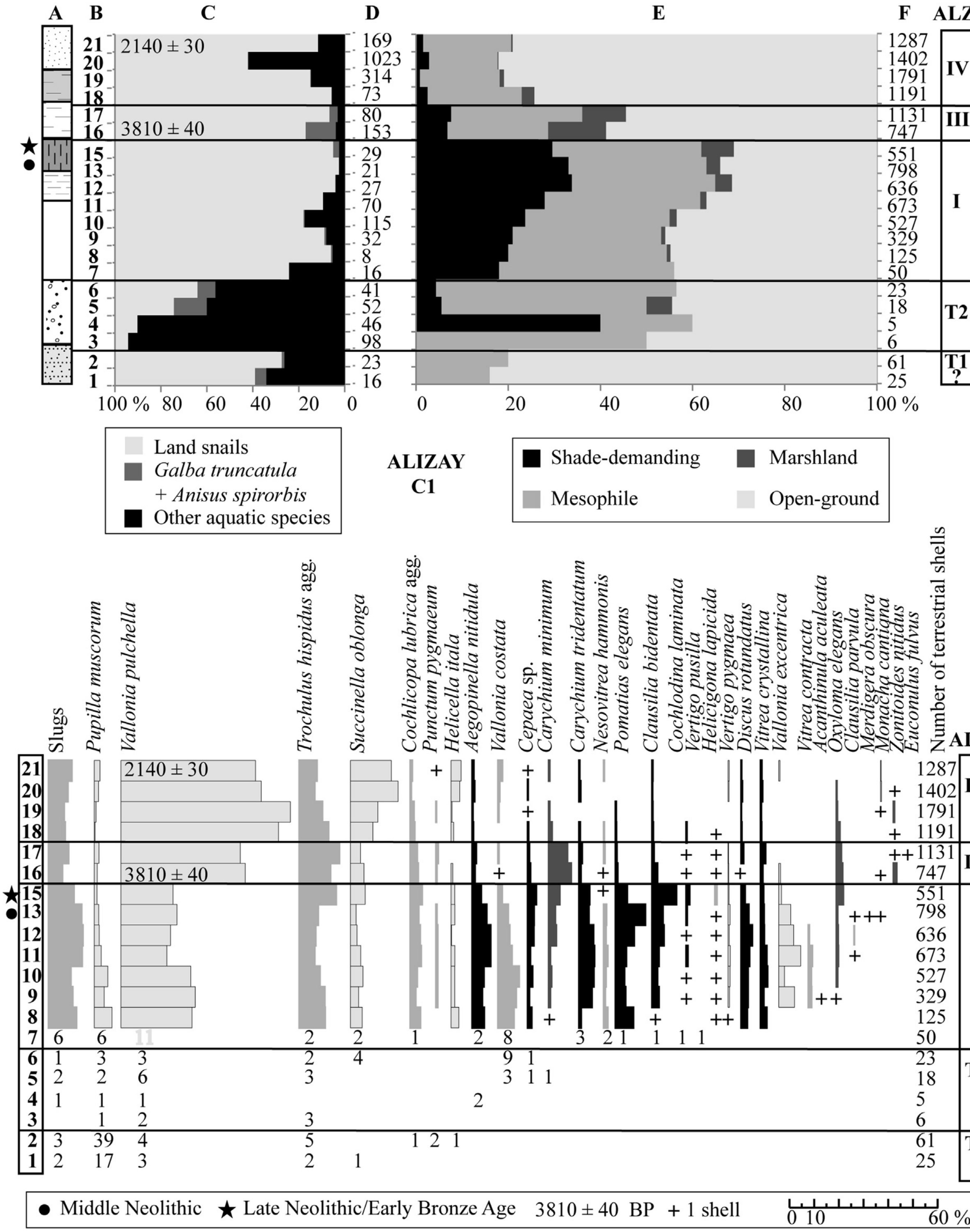

Fig. 7. Alizay, *Le Port au Chanvre*, profile C1. Ecological and specific composition of malacological assemblages. A: Schematic stratigraphical profile (see Fig. 3); B: Sample number; C: Frequency and distribution of aquatic shells; D: Number of aquatic shells; E: Ecological classification of terrestrial shells; F: Number of terrestrial shells.

artefacts and structures such as hearths have been found. In the Paris Basin, many important sites dating from the middle Neolithic have been discovered close to river channels, as at Alizay. For example, the Parisian site of *Bercy* (Lanchon and Marquis, 2000) and that of Louviers *La Villette* (Giligny, 2005), near Alizay, stand out because of the remarkable preservation of some wooden constructions, such as dugouts at Paris *Bercy* (Arnold, 1998; Lanchon and Marquis, 2000) and wooden paths built across a marshy area at Louviers (Giligny, 2005). Assemblages dominated by shade-demanding taxa have nevertheless extended until 4213 ± 77 BP at Saint-Germain-le-Vasson, in Lower Normandy (Limondin-Lozouet and Preece, 2004; Limondin-Lozouet et al.,

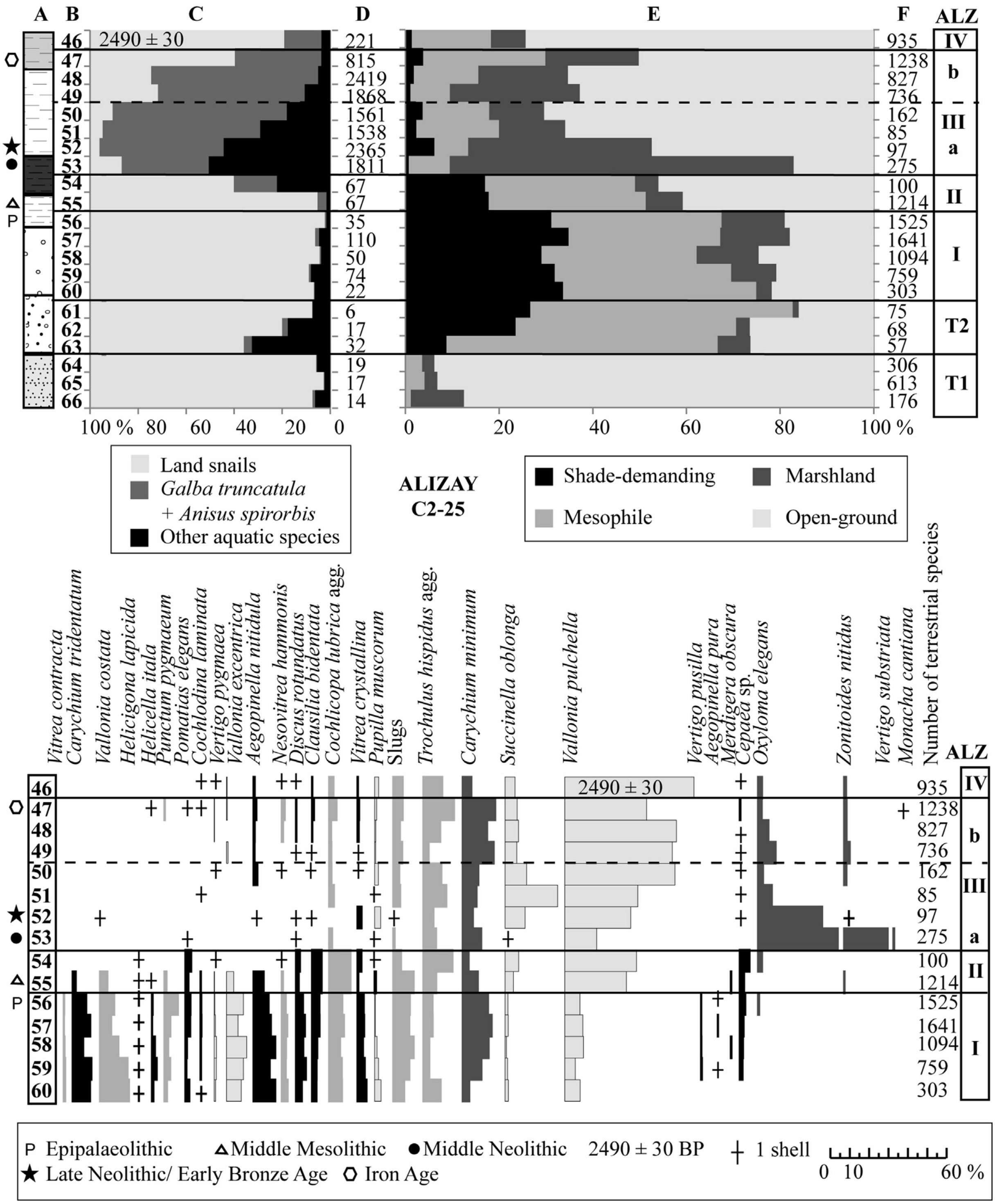

Fig. 8. Alizay, *Le Port au Chanvre*, profile C2-25. Ecological and specific composition of malacological assemblages. A: Schematic stratigraphical profile (see Fig. 3); B: Sample number; C: Frequency and distribution of aquatic shells; D: Number of aquatic shells; E: Ecological classification of terrestrial shells; F: Number of terrestrial shells.

2005) and until 4362 ± 51 BP at Daours, in the Somme basin (Limondin-Lozouet et al., 2013). However, these sequences relate to tufa environments, which are likely to differ from the floodplain habitats under discussion here. They are rarely associated with human settlements and have often ceased to form, depending on localities, between 4500 and 2500 cal BC, during the Neolithic. In the Seine floodplain, at Paris *Héliport/Farman* and Alizay, moist conditions have lasted the duration of the Subboreal, between the late Neolithic and the end of the Bronze Age. Despite this increased moisture, which would have been beneficial to the vegetation growth, the malacozones attributed to the Subboreal nevertheless reflects more open environments. As a result, human impact seems to be the main factor responsible for maintaining the open character of environments. The alluvial landscapes are progressively cleared of trees but they seem to be too unstable for sedentary settlements and too poorly drained for cultivation.

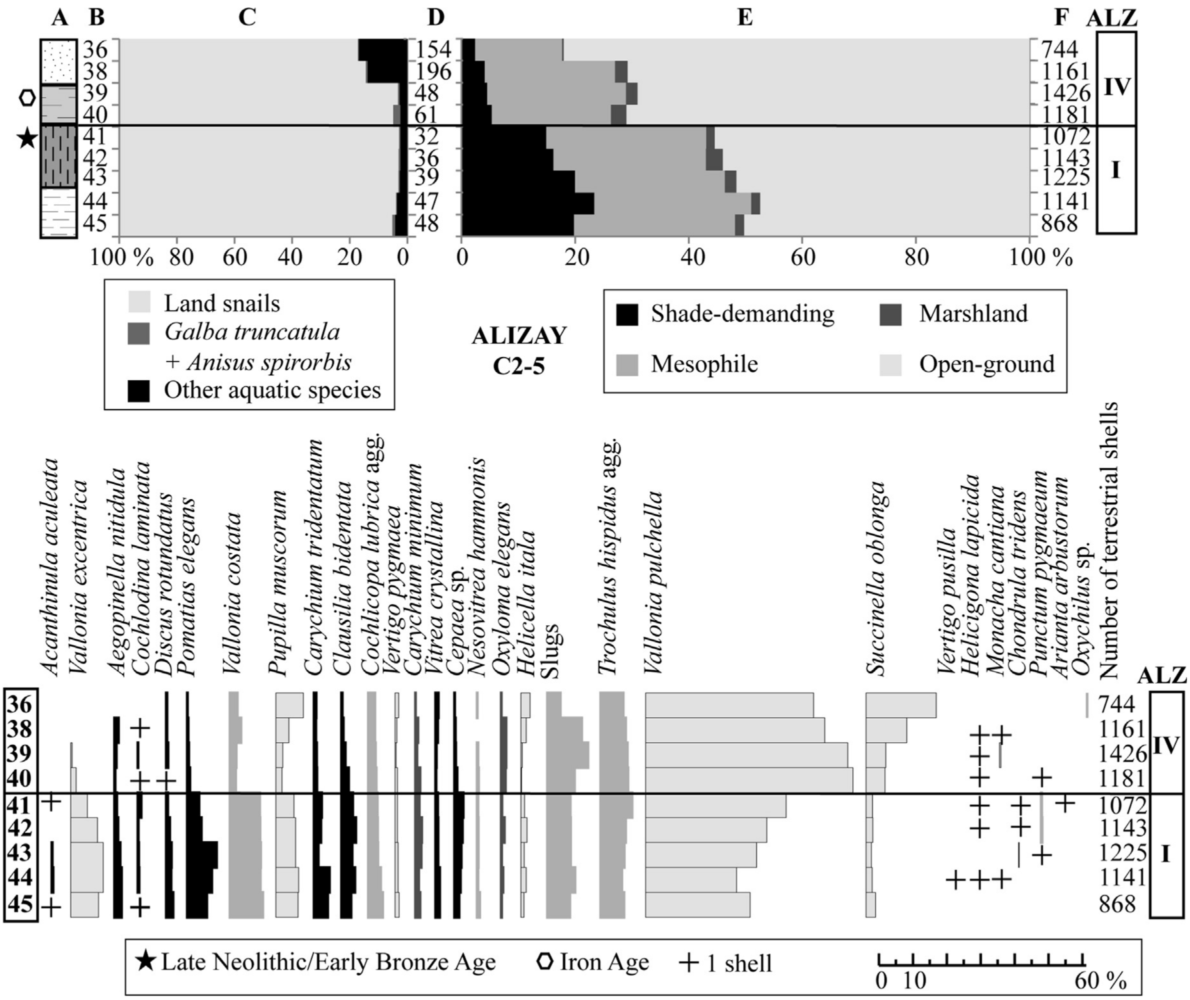

Fig. 9. Alizay, *Le Port au Chanvre*, profile C2-5. Ecological and specific composition of malacological assemblages. A: Schematic stratigraphical profile (see Fig. 3); B: Sample number; C: Frequency and distribution of aquatic shells; D: Number of aquatic shells; E: Ecological classification of terrestrial shells; F: Number of terrestrial shells.

4.5. Subatlantic chronozone

During *PHF-III* and *ALZ-IV*, species from open-ground increase while those from wetlands decrease. In other words, the ground humidity declines as the vegetation openness intensifies. One single species (*V. pulchella*) is predominant and this impoverishment of the malacological diversity results from a comparable homogenization of the vegetation cover, which is clearly dominated by grass. According to the position of archaeological remains and the results of radiocarbon dates, this environmental change occurs at the end of the Subboreal. It is dated from 2805 ± 50 BP at Paris *Héliport/Farman* (Table 1) and from 2760 ± 15 BP at Alizay (Table 2).

5. Discussion

Here the results obtained from molluscan studies in the Paris Basin are compared with those obtained from pollen and put into a European perspective (Fig. 9).

5.1. Malacology and palynology in the Paris Basin

In the Paris Basin, a malacological reference framework has been constructed on the basis of the faunal successions derived from tufa deposits. Regarding the first half of the Holocene, the malacological successions from these deposits often reflect the development of closed woodlands in the small valleys (Limondin-Lozouet et al., 2005, 2013), while the large floodplain of the Seine seems dominated by open woodlands. In the regional pollen data synthesis, arboreal pollen are predominant (Leroyer, 1997, 2003, 2006). During the Boreal, in the regional pollen diagrams, the high frequencies of *Corylus*, which is a heliophilous shrub, may determine the open character of the malacological assemblages of floodplain deposits observed at Alizay and Paris. The forest optimum recorded in tufa deposits is probably absent of these sites because of a hiatus, corresponding to most of the Atlantic chronozone.

In the regional pollen diagrams, the Subboreal is characterized by an overwhelming predominance of *Alnus*, a riparian taxon (Leroyer, 1997, 2003, 2006). The high frequency of *Alnus* indicates moist conditions, which is in good agreement with the malacology, but this may nevertheless be deceptive since *Alnus* is greatly over-represented because it produces copious quantities of pollen relative to other taxa and also because of the proximity of the sampling profile to the *Alnus* pollen source (David et al., 2012). The high frequency of *Alnus* pollen eventually masks the declines of *Ulmus*, *Tilia* and *Quercus*, which are nevertheless clearly discernible in pollen diagrams. In addition, these decreases are contemporaneous with an increase in ruderal plants, which are species of wasteland and thus evidence of human impact (Leroyer, 2003, 2006; Leroyer and Allenet, 2006). This clearance of the landscape is much more noticeable in the malacological assemblages.

The latter thus enable the recognition of a lateral variability of the vegetation cover, which would be hard to see from the pollen analysis alone. Beyond the riparian forests are marshy and grassy meadows, which are certainly useful for cattle grazing but hostile for permanent settlements because of seasonal flooding. This instability is reflected by the incision and the infilling of successive channels in the Seine floodplain, such as observed at Alizay *Le Port au Chanvre*.

During the Subatlantic chronozone, *Alnus* declines and the human impact becomes obvious in pollen diagrams with significant increases of both cereals and ruderal plants (Leroyer, 1997; Leroyer and Allenet, 2006). This development is coincident with an increase of minerogenic sediments in the Seine floodplain (Figs. 2c and 3c). The input of minerogenic sediments consists mainly of alluvium, which are probably deposited only during major flood events, as indicated by the predominance of land snails in the malacological assemblages. Floodplains appear to be less inhospitable for permanent settlements than during the Subboreal. However, the archaeological remains are still scarce; but this scarcity should not obscure the intense use of floodplains for agricultural activities.

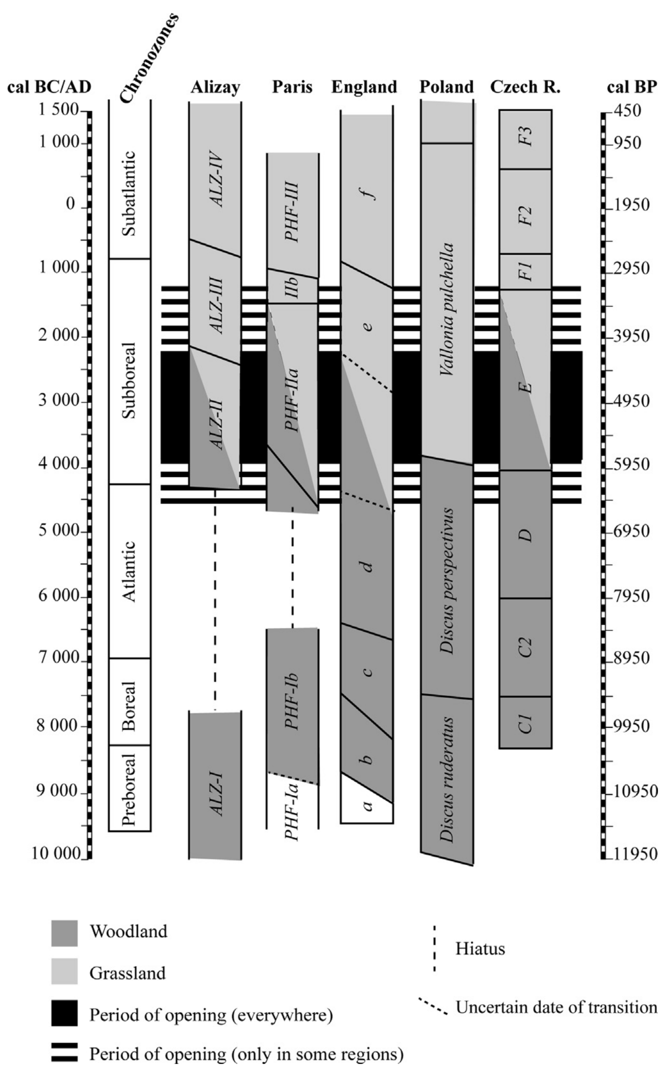

Fig. 10. Malacological assemblages from Paris *Héliport/Farman* and Alizay *Le Port au Chanvre*, shown with respect to chronozones (from Mangerud et al., 1974; calibrated by Walanus and Nalepka, 2010), and compared with malacozones from England (Preece and Bridgland, 1998), Poland (Alexandrowicz, 2009) and Czech Republic (Horáček and Ložek, 1988).

5.2. Holocene molluscan successions in Europe

The United-Kingdom has been the subject of numerous malacological analyses, particularly between the 1960s and the 1990s. In England, studies have mainly focused on southern and central regions, as Kent (Kerney et al., 1964, 1980; Preece and Bridgland, 1998, 1999), and Northamptonshire (Meyrick and Preece, 2001). In these regions, tufa sequences have yielded series of malacological reference. In Kent, the malacological framework, which is based on a large number of sequences, is consistent with the landscapes changes recorded in local pollen diagrams (Preece and Bridgland, 1998, 1999). Regarding the Holocene, six malacozones have been defined (Fig. 10). Up to the zone *e*, landscapes are dominated by woodlands. An increasing clearance of the vegetation cover is then recorded during the Subboreal. Its chronology varies locally, depending on the proximity of archaeological settlements, but it generally occurs between 4500 and 2500 cal BC. From that latter date, environments appear to be largely cleared of trees. This dynamic is consistent with the environmental trajectory observed, in parallel, in the Seine floodplain.

In Poland, many Holocene malacological data have been collected by Stefan Witold Alexandrowicz and then by Witold Pawel Alexandrowicz, especially in the southeast quarter of the country, in the upstream basin of the Vistula. These analyses have been conducted in various contexts, like plateaus, slopes and floodplains, in sediments such as loess, tufa or alluvium. A synthesis of the malacological data derived from tufa deposits has enabled the construction of a malacological framework of reference for these contexts (W.P. Alexandrowicz, 2004). A more comprehensive framework that integrates data from alluvium has recently been constructed (W.P. Alexandrowicz, 2009). It demonstrates that landscapes are everywhere largely dominated by forests until around 3961–3813 cal BC (5100 BP; W.P. Alexandrowicz, 2009). As early as the beginning of the fourth millennium BC, woodlands decline in favour of grasslands. This change is not recorded everywhere, e.g. the Carpathians are spared. In reality, it depends on the intensity of human impact in the different studied regions. Moreover, the pace of land clearings is not detailed. The latter are certainly not synchronous at all sites, as observed in southern England (malacozone *e*). Finally, it is interesting to note that, in Poland, the iconic species of open environments is, as in the Seine basin, *V. pulchella*. This similarity is due to comparable investigated contexts, in lowlands.

In Czech Republic, Vojen Ložek was the first to build a malacological framework of reference in Europe (Ložek, 1964). Since then, this reference system has been reworked and has been the subject of syntheses published in English (Ložek, 1982, 1993; Horáček and Ložek, 1988). In floodplains, woodlands are more or less gradually replaced by grasslands during the fourth, third and second millennia BC (zone *E*). This evolution is reminiscent of that observed in the Seine basin (Fig. 10). However, in Czech Republic, the zone *F*, which starts from ~1250 cal BC, has then been divided into three subsets because of the gradual arrival of various alien species. This accuracy has not been reached in the Seine valley, perhaps because of the too condensed nature of the studied sedimentary archives.

6. Conclusion

The sites of Paris *Héliport/Farman* and Alizay *Le Port au Chanvre* yield similar malacological assemblages despite being separated by ~100 km. The malacological assemblages follow common ecological trajectories in these parts of the Seine floodplain. Looking at the Holocene in more detail, a three stage development of environments can be observed. The first zone covers the early Holocene

and reflects diverse vegetation providing a patchwork of habitats for snails. At Alizay, the interpretation of the early part of the succession is nevertheless complicated by the presence of Holocene elements into sediments of supposed Younger Dryas age. At the site of Paris *Héliport/Farman*, a two stage development is observed in the first zone, attributed to the early Holocene attribution. After a long hiatus corresponding to much of the Atlantic, the second environmental episode, is marked by the progressive development of wet grasslands and by the local development of swampy areas. An increasing openness of the vegetation cover and a reduction of moisture (with the disappearance of marshlands) are then recorded in the third episode, attributed to the late Holocene. These developments are largely complementary with the results obtained from regional pollen analyses and consistent with the molluscan assemblages from other European regions. It is striking that the molluscan assemblages share a similar environmental trajectory from the Seine basin to the Vistula, from England to Czech Republic. The responses of floodplain environments to climate variations and to disturbances resulting from human impact have to be investigated. If human pressure probably explains the gradual landscape openness, the common pace of this evolution is more difficult to explain in regions with such different sedimentary, topographical, ecological and archaeological contexts.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.09.011.

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